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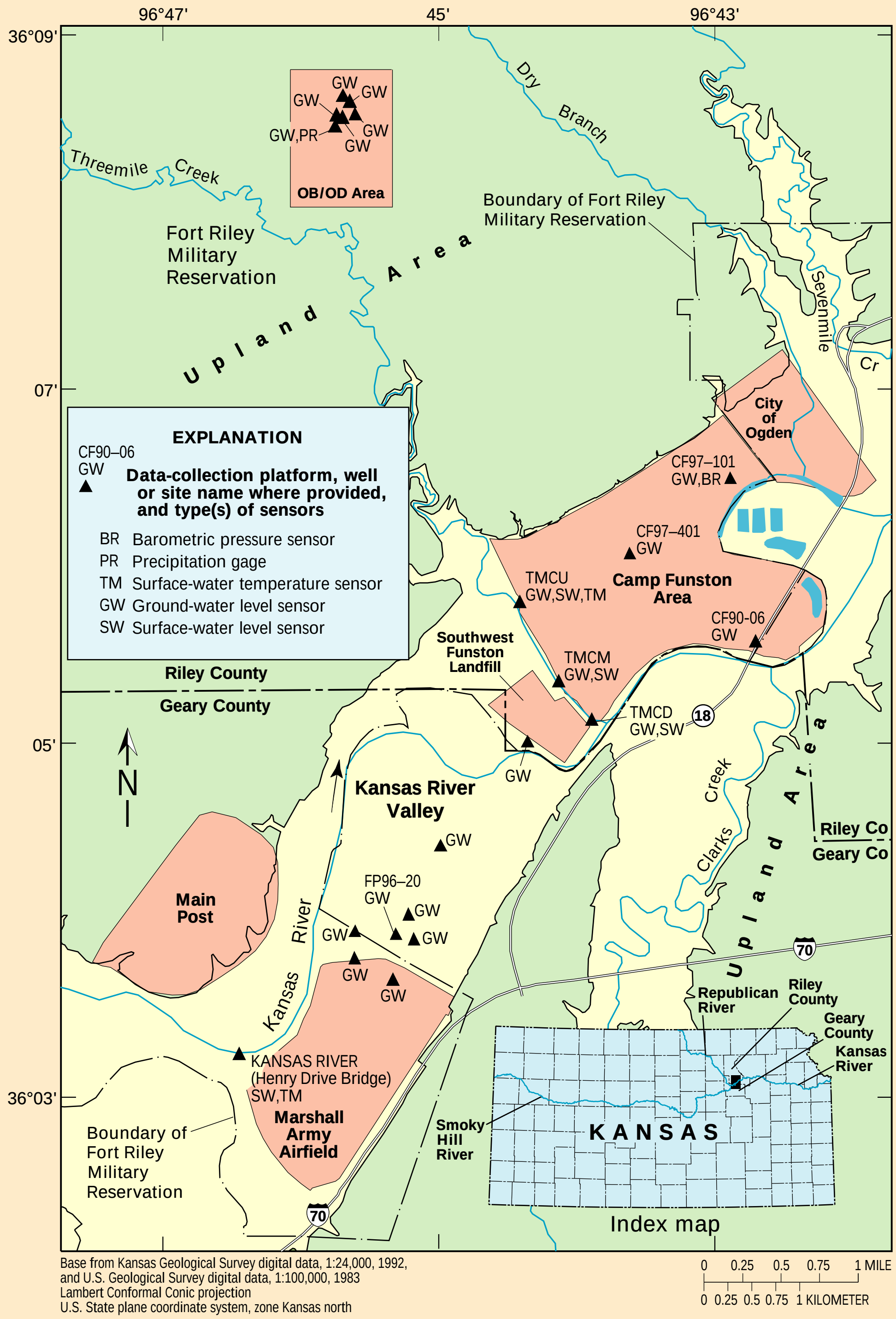
Analysis of Water-Level Data and Ground-Water Flow Modeling at Fort Riley, Kansas

—N.C. Myers, P.J. Finnegan, and J.D. Breedlove

The purpose of this report is to describe how analyses of periodic and continuous ground- and surface-water-level data collected at Fort Riley, Kansas, and a ground-water flow model can be used to: (1) characterize directions of ground-water flow, (2) assess the interaction of ground and surface water, and (3) estimate aquifer parameters. This work is being done by the U.S. Geological Survey in support of the U.S. Army's Installation Restoration Program (IRP) at Fort Riley.

Background

Characterization of ground-water movement in the Kansas River Valley and in upland areas (Breedlove and others, 1998) near the river valley at Fort Riley in northeast Kansas (fig. 1) is important for understanding the movement of ground-water contaminants. The Kansas River alluvial aquifer consists of sand and gravel commonly 0 to 60 feet thick and occupies the Kansas River Valley. Precipitation-driven changes of water levels in the Kansas River predominantly affect ground-water movement in the Kansas River alluvial aquifer. Because of the complex nature of the ground-water system in the area, periodic (measured two to three times per year) and continuous (measured hourly) ground- and surface-water-level measurements are necessary to develop and refine concepts of ground-water flow and potential contaminant transport at Fort Riley. These data also are necessary for developing a computer model of ground-water flow in the Kansas River alluvial aquifer.



Base from Kansas Geological Survey digital data, 1:24,000, 1992, and U.S. Geological Survey digital data, 1:100,000, 1983
Lambert Conformal Conic projection
U.S. State plane coordinate system, zone Kansas north

Figure 1. Location of data-collection platforms (DCP's) at Fort Riley Military Reservation in and near Kansas River Valley, northeast Kansas.

U.S. Geological Survey Federal-State Cooperative Water-Resources Program and U.S. Department of Defense Installation Restoration Program

The U.S. Geological Survey (USGS) Federal-State Cooperative Water-Resources Program (Cooperative Program) was established in Kansas in 1895 to provide data on surface- and ground-water resources and water quality. These data form the foundation for many of the Nation's water-resources management and planning activities. Cooperative Program priorities are developed in response to mutual Federal, regional, State, and local concerns.

The U.S. Department of Defense established the Installation Restoration Program (IRP) in 1975 to provide guidance and funding for the investigation and remediation of hazardous-waste sites at military installations throughout the United States. At Fort Riley, the U.S. Army's IRP is carried out by the Directorate of Environment and Safety in accordance with Federal, State, and local regulations.

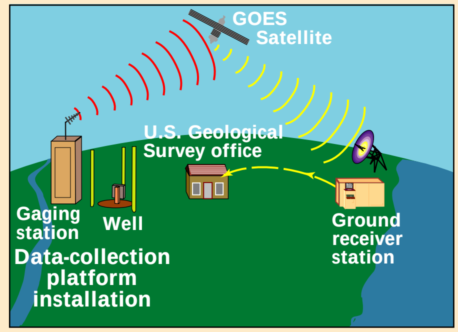


Figure 2. Near-real-time data-collection and transmission system.

Near-Real-Time Data Collection and Transmission System

Water-level data have been collected periodically since 1992 from wells and surface-water bodies in the Kansas River Valley and upland areas at Fort Riley, generally in conjunction with ground-water-quality sampling activities. Continuous, near-real-time, water-level data, measured in selected wells (fig. 1) using automated water-level sensors, are recorded by data-collection platforms (DCP's) and transmitted via Geostationary Orbiting Environmental Satellite (GOES) and ground-receiver stations to the USGS office in Lawrence, Kansas (fig. 2). The data then are stored in the NWIS (National Water Information Storage) data base. The DCP at the Kansas River (Henry Drive Bridge) (fig. 1) was installed in 1963 in cooperation with the State of Kansas (see text inset above). Other DCP's at monitoring wells and along Threemile Creek at Fort Riley were installed in support of the U.S. Army's IRP.

Many of the DCP's at Fort Riley are configured to record and transmit near-real-time ground-water-level data from a single well (fig. 3). Equipment at these single-sensor installations include the DCP, a ground-water-level sensor, solar panel, 12-volt battery, ground rod, and GOES antenna. All but the ground-water-level sensor are housed in or are attached to an aluminum shelter (fig. 3). Where feasible, and to decrease equipment costs, a single DCP can be configured to record and transmit data from multiple sensors, such as a surface-water-level sensor in the creek and four ground-water-level sensors in wells (fig. 4) at each of the three Threemile Creek gaging stations (sites TMCU, TMCM, and TMCD; fig. 1). In addition to water-level sensors, DCP's can be configured to record and transmit data from other types of environmental sensors, such as rain gages, barometric pressure sensors, or water-quality monitors.

Presently (December 1998), 21 DCP's at Fort Riley record and transmit near-real-time water levels from 4 surface-water sites and 38 monitoring wells or piezometers, water temperatures from 2 surface-water sites, barometric pressure from 1 site, and precipitation from 1 site (fig. 1). The DCP's transmit data every 4 hours or, at the Open Burn/Open Demolition (OB/OD, fig. 1) area, once a day.

Analysis of Water-Level Data

Analysis of periodic and continuous water-level data can provide information about changes of ground-water flow over space and time. Periodic water-level data can be used to construct water-table maps that show spatial variations of ground-water elevations. These spatial variations, in turn, can be used to estimate directions of ground-water flow and potential contaminant movement and the degree of interaction between ground and surface water. Water-table maps show spatial variations in ground-water elevations at a point in time. In contrast, continuous water-level data (hydrographs) show temporal variations in ground-water elevations at a point in space. Hydrographs can show how ground water responds to changing river stage, aquifer recharge rates, barometric pressure, well pumping or injection rates, and other stresses imposed on the ground-water system.

Periodic water-level data obtained from wells and surface-water bodies at the Southwest Funston Landfill and in the Camp Funston Area (fig. 1) were used to construct water-table maps. Two

Figure 3. Single-sensor data-collection platform (DCP) installation at well FP96–20 (fig. 1).

Figure 4. Multiple-sensor data-collection platform (DCP) installation at site TMCU (fig. 1).

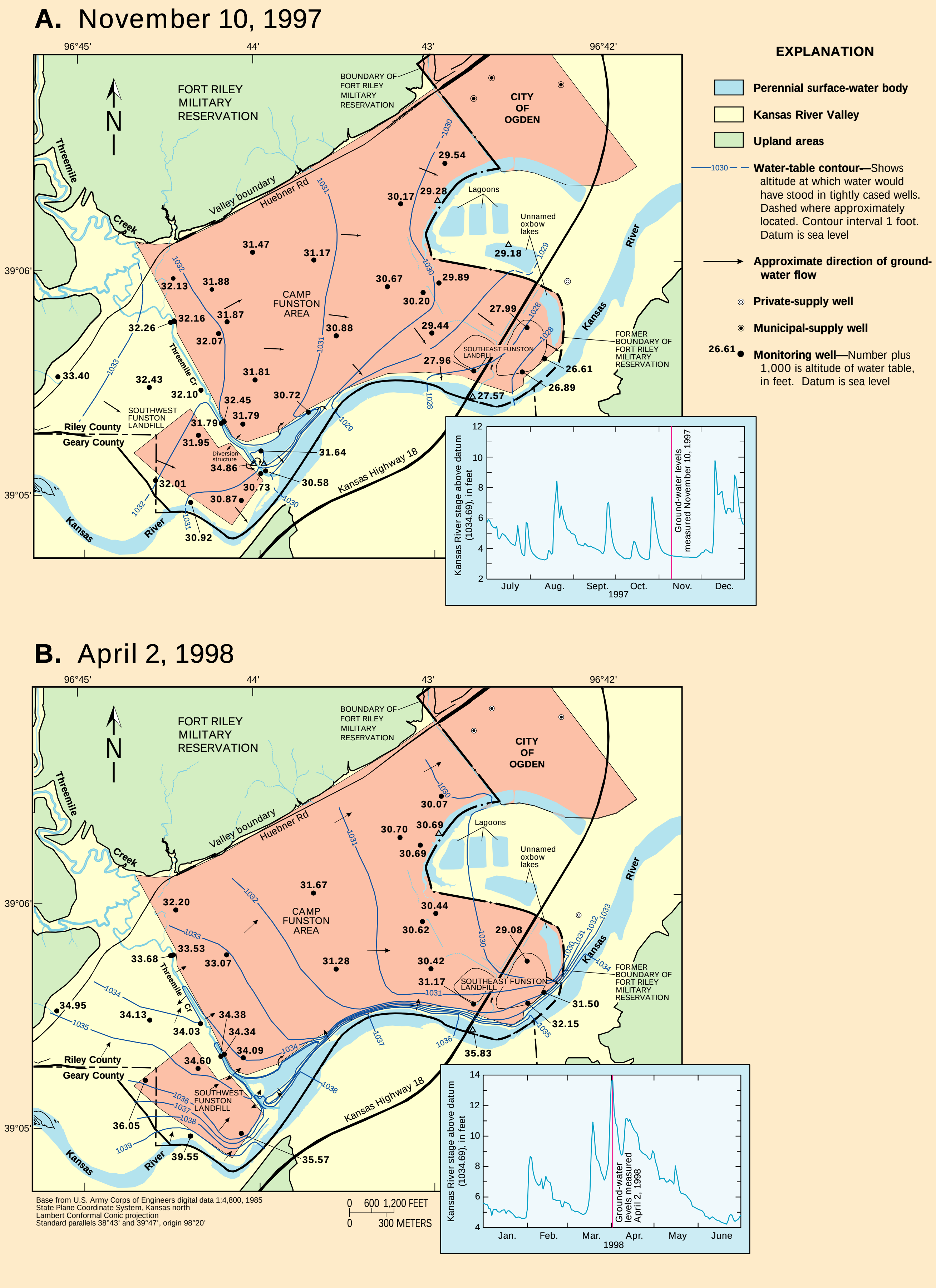


Figure 5. Configuration of water table in alluvial aquifer for (A) November 10, 1997, and for (B) April 2, 1998, for the Southwest Funston Landfill and Camp Funston Area, and (insets) Kansas River stage before, during, and after ground-water-level measurement, July–December 1997 and January–June 1998.

examples of these maps are shown in figures 5*A* and 5*B*. These maps show two very different configurations of the water table and ground-water flow. On November 10, 1997 (fig. 5*A*), ground-water flow generally was toward the southeast, whereas on April 2, 1998 (fig. 5*B*), ground-water flow generally was toward the northeast.

Water-table maps also can indicate relationships between ground- and surface-water bodies. For April 2, 1998, water-table contours indicate that near the Kansas River the water table slopes away from the river and that surface water was seeping from the river to the alluvial aquifer. For November 10, 1997, water-table contours indicate that near the river the water table slopes towards the river and that ground water was seeping from the alluvial aquifer to the Kansas River. The deflections in water-table contours near Threemile Creek indicate that for both dates creek water was interacting with ground water in localized zones on each side of the creek. These maps also indicate that the configuration of the water table and ground-water flow vary substantially over time but do not indicate the frequency or duration with which either configuration occurs. Depending on assumptions as to the frequency and duration of each configuration, widely varying estimates of ground-water flow directions and contaminant movement could be obtained.

The availability of continuous river-stage data improves the estimate of ground-water flow directions and contaminant movement by putting the two water-table maps into their proper context in this continuously changing hydrologic environment. Comparisons of water-table maps, such as those in figures 5*A* and 5*B*, to Kansas River stage hydrographs (insets on figures 5*A* and 5*B*) show that when water in the Kansas River is high (April 2, 1998), ground water flows generally toward the northeast, away from the river, and when water in the river is low (November 10, 1997), ground water flows generally southeast, toward the river. By inspection of the Kansas River stage hydrographs (insets, figs. 5*A* and 5*B*), it is evident that the frequency and duration of high and low river stage are variable. However, on average, periods of low river stage occur more often and last longer than periods of high river stage, and therefore, southeasterly ground-water flow and contaminant movement also would occur more often than northeasterly flow and contaminant movement.

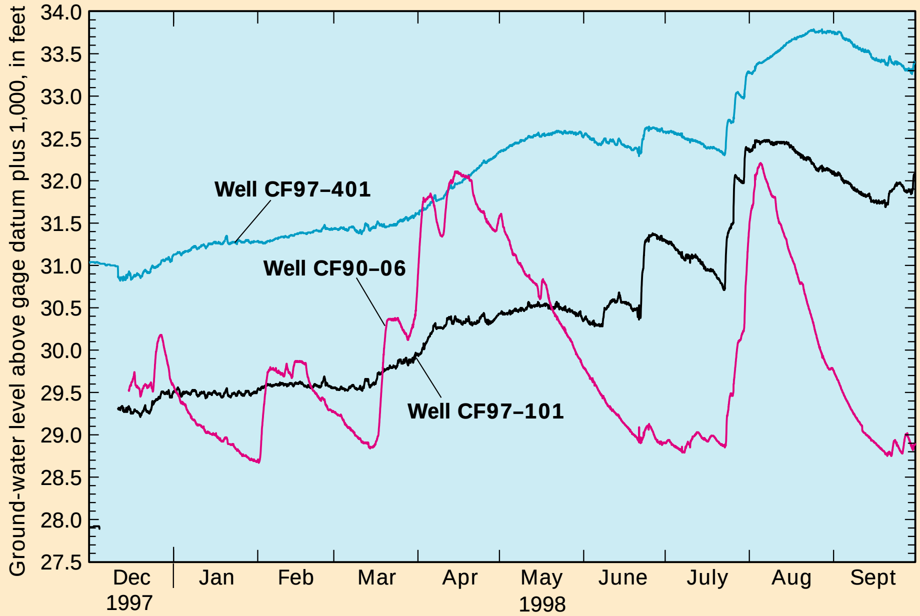


Figure 6. Water levels in wells CF97–101, CF97–401, and CF 90–06, December 1997–September 1998. Location of wells shown in figure 1.

Continuous ground-water-level data from wells also can be used to improve estimates of ground-water flow directions and potential contaminant movement. Computations using continuous ground-water-level data for December 1997 through September 1998 (fig. 6) show that in the area encompassed by wells CF97–101, CF97–401, and CF90–06 (fig. 1) the most frequently occurring direction of ground-water flow was to the southeast (fig. 7). The mean water-table gradient (change in water-table altitude per distance of travel) was steepest in the southeasterly direction as well.

The information from figure 7 can be used to determine the fastest rate of ground-water movement. The average linear velocity of ground-water flow is related to water-table gradient (mean gradient in figure 7) by $\bar{v} = (-K/n)i$ (Freeze and Cherry, 1979), where $\bar{v}$ is the average linear ground-water velocity, K is the hydraulic conductivity, n is aquifer porosity, and i is the water-table gradient. Assuming that K/n is constant for an aquifer, then ground-water flow velocity is directly proportional to the water-table gradient. Thus, in the area encompassed by wells CF97–101, CF97–401, and CF90–06, the larger water-table gradients are directed to the southeast, indicating faster ground-water flow towards the southeast than to the northeast. Assuming K=500 feet per day and n=0.2, and on the basis of the average gradient (0.000612 foot per foot), the average velocity of ground-water flow in the area encompassed by these wells would be about 1.5 feet per day to the east-southeast. Contaminant movement generally would be in the same direction as overall ground-water flow; however, estimated movement would vary somewhat depending on the location of the wells selected for analysis.

Continuous ground-water-level data can be used to develop an improved understanding of how ground-water conditions respond to changes in river stage and how far and how quickly these changes propagate through the aquifer. Figure 8 shows how ground-water levels in wells 500, 1,500, and 5,000 feet from the Kansas River respond to changes in river stage. The well closest to the river (at site TMCD, fig. 1) responds the most quickly and with the greatest water-level change, whereas the well farthest from the river (at site TMCU, fig. 1) responds more slowly and with much less water-level change. Water-level responses such as these can be used to calculate aquifer parameters such as diffusivity, which is the ratio of aquifer hydraulic conductivity to aquifer storage (Pinder and others, 1969; Reynolds, 1987). Water-level responses in wells also can yield other important information such as the existence of multiple recharge sources.

Ground-Water Flow Model

As discussed previously, both periodic and continuous water-level data can yield valuable information about ground-water flow, but this information is limited either in time or in space. A ground-water flow model, designed to simulate ground-water flow in an aquifer, integrates both time and space, can be used for a more comprehensive analysis of ground-water flow, and can simulate the effects of past or future hypothetical conditions on ground-water flow. A ground-water flow model can show the paths that particles of water follow as they flow through an aquifer and, generally, show the path that a conservative (nonreactive) chemical might follow through an aquifer. However, a ground-water flow model cannot simulate contaminant transport because the model does not account for dispersion, retardation, or attenuation of contaminants.

A ground-water flow model, being developed by the USGS to simulate ground-water flow in the Kansas River alluvial aquifer at Fort Riley, extends from the confluence of the Smoky Hill and Republican Rivers to about 2.5 miles downstream from the city of Ogden (fig. 9). The model area incorporates several sites where ground-water contaminants have been detected at Fort Riley. Particle tracking will be used to estimate ground-water flow paths for past and future hypothetical conditions. Of particular interest relevant to the Camp Funston Area is the source of ground water being pumped from Ogden's municipal-supply wells (fig. 5). Backward particle tracking will be used to trace ground water from the vicinity of Ogden's wells backwards in time to points of recharge. The model also will be used to provide data input for boundary conditions of smaller models developed for site-specific studies at Fort Riley.

Ground-water flow models need to be calibrated if they are to reliably simulate observed hydrologic conditions. Model calibration is a process of adjusting model parameters so that simulated and observed hydrologic conditions are similar. Periodic and continuous water-level data can be used in model calibration. For example, measured Kansas River stage and ground-water-level data (fig. 8) will be compared to simulated Kansas River stage and ground-water-level data. If differences between measured and simulated water levels exceed an acceptable margin of error, then model parameters, such as aquifer hydraulic conductivity, streambed hydraulic conductivity, locations and nature of simulated aquifer boundaries, or model stresses, such as recharge and

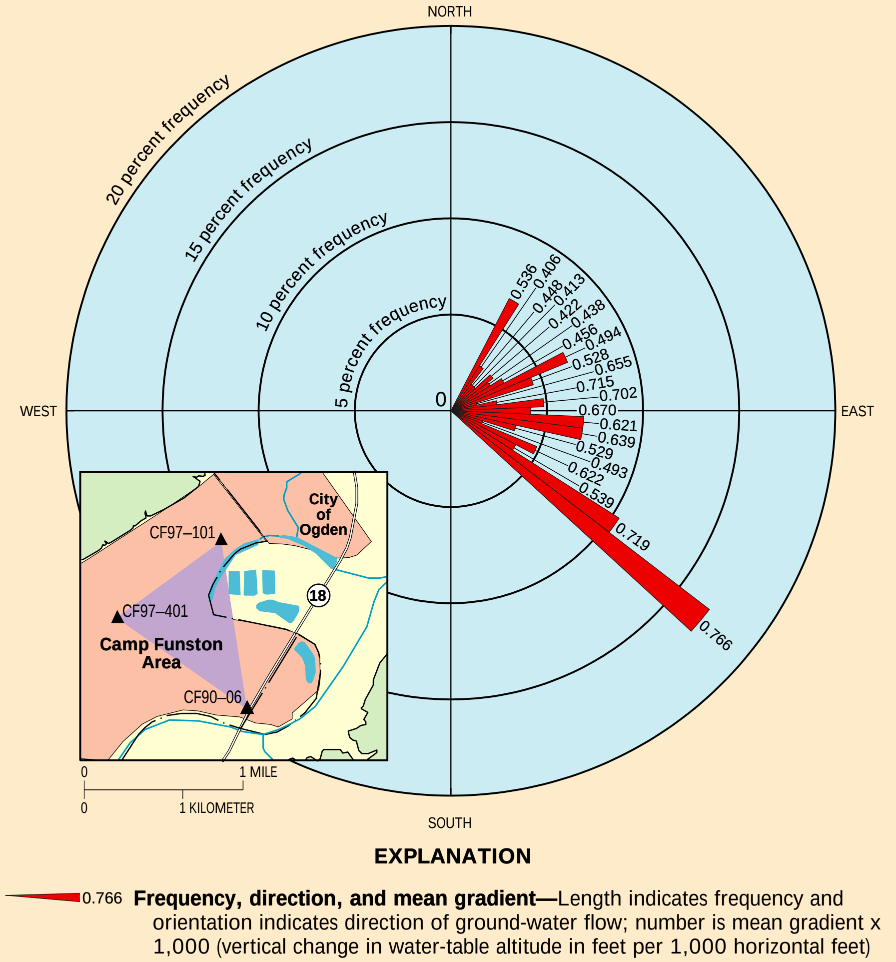


Figure 7. Map view of frequency and direction of ground-water flow in area encompassed by wells CF97–101, CF97–401, and CF90–06, and gradient x 1,000, December 1997–September 1998. For example, southeast ground-water flow occurred about 17 percent of the time, and observations with this direction had a mean gradient of 0.000766 foot per foot. Location of wells shown on inset map.

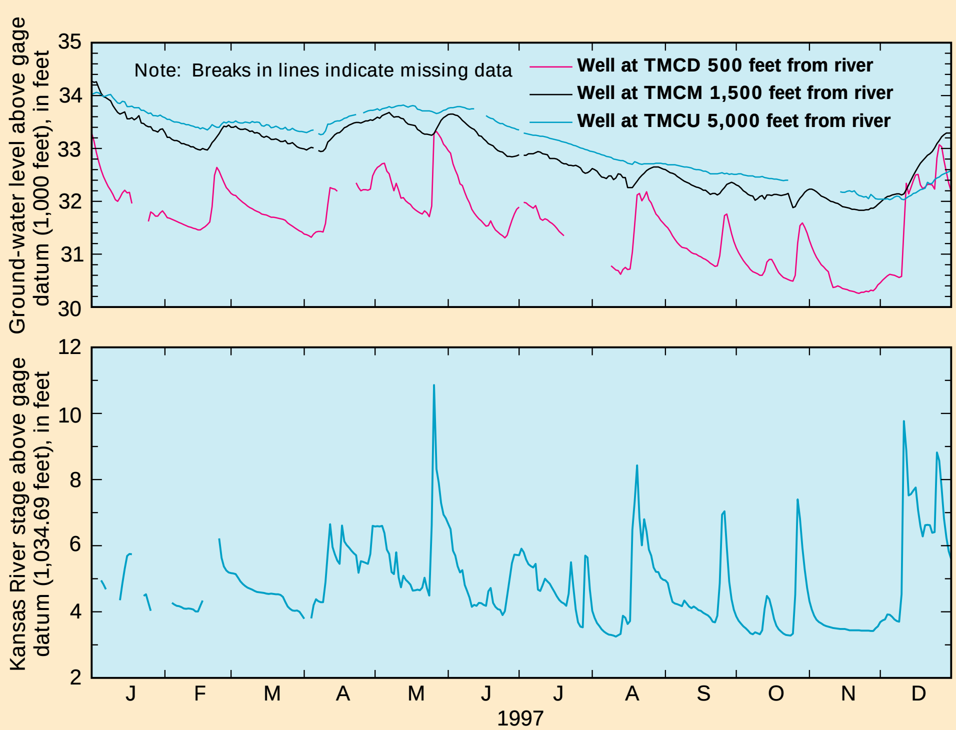


Figure 8. Kansas River stage at Henry Drive Bridge and ground-water levels in wells at various distances from the Kansas River, 1997. Location of gage and wells shown in figure 1.

boundary inflow, will be adjusted to provide a better calibration. Changes in model parameters also may be made as a result of comparisons of differences between water levels measured in wells completed in shallow (water table) and deep (at underlying bedrock) zones of the alluvial aquifer (fig. 10) and simulated water levels in shallow and deep model layers. Changes may be made to simulated Threemile Creek streambed hydraulic conductivity if simulated gains or losses of creek water do not reasonably match measurements of gains or losses of creek water. Adjustments to model parameters, stresses, and boundaries will be limited within reasonable ranges that are based on available information.

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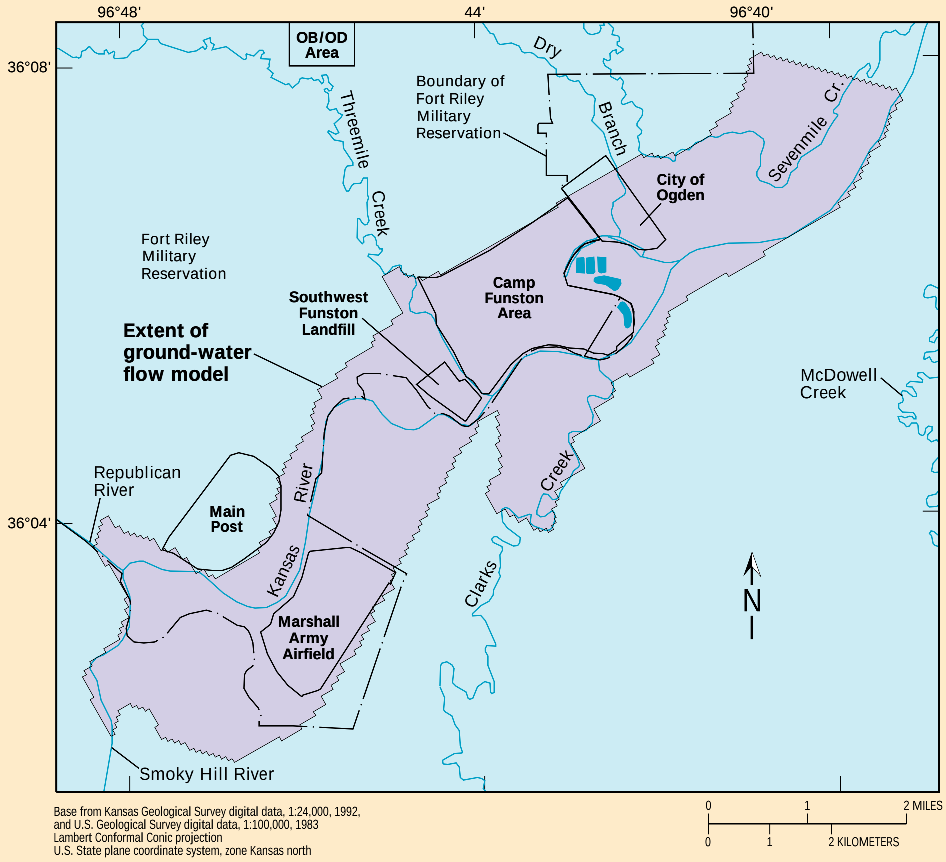

Figure 9. Extent of ground-water flow model being developed.

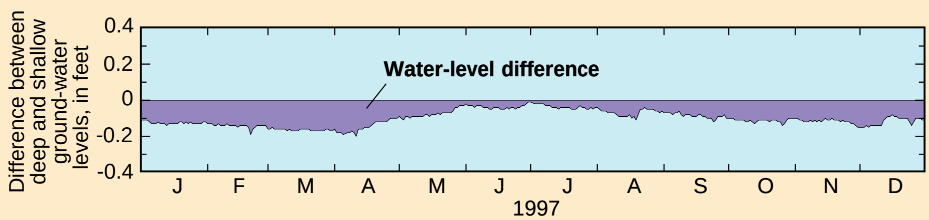

Figure 10. Ground-water-level differences between deep and shallow alluvial aquifer zone wells near Threemile Creek (wells at site TMCM, fig. 1).

For more information contact please contact:

District Chief
U.S. Geological Survey
4821 Quail Crest Place
Lawrence, Kansas 66049–3839
(785) 842–9909